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# Smart Home Renewable Energy Management System

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**Abstract**

One of the major attribute of the smart grid is to integrate renewable and storage energy resources at the consumption premises. This paper presents the design, implementation and testing of an embedded system that integrates solar and storage energy resources to a smart home. The proposed system provides and manages a smart home energy requirement by installing renewable energy; and scheduling and arranging the power flow during peak and off-peak period. In addition to that, a two-ways communication protocol is developed to enable the home owner and the utility provider to better optimize the energy flow and the consumption efficiency. A prototype for the proposed system was designed, implemented and tested using a controlled load bank to simulate a scaled random real house consumption behavior. Three different scenarios were tested and the results and findings are reported.
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*Keywords: Automatic meter reading, component, energy magmanet system, smart gird, samrt home, solar energy*

## 1. Introduction

A smart home energy management system is a system capable of exchange commands between households and energy providers to optimize the energy consumptions. This type of collaboration between energy shareholders result in reducing the consumer electrical bill and better manage the peak loads by the electrical utilities [1]. Smart Grid is one of emerging R&D concepts that integrates traditional electrical grid with the recent development of information and telecommunications technologies to improve the efficiency of power generations, transmissions, distributions and consumptions systems [2-6]. One of the key features of the smart grid is the integration of renewable and storage energy resources at the consumption side [4-8]. Another key feature is to enable consumers and utility to communicate with each other to share the responsibility of managing the power flow and consumptions [4-8]. This

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paper presents the design of home energy management system that integrates the power resources from the traditional grid and renewable energy sources namely; solar energy and storage energy. A single chip microcontroller is used to multiplex the three power sources to supply the house with its required power based on a communication between the utility and the house owner. The communication protocol, energy flow, demand-response and billing system hardware and software are developed using a home gate and utility server. The home gateway (H-Gateway) is a single chip embedded system integrated with GSM modem and it is installed at the consumer premises. The utility server (U-Server) is a high-end PC and it is installed at the utility headquarter. Consumer and Utility can manage the energy follow and consumption by exchange message between the H-Gateway and U-Server via the GSM modem. Fig. 1 shows the proposed system conceptual model [8].


Fig. 1. Proposed system conceptual model.

## 2. System Requirements

The functional and non-functional requirements of the system are described. To design an optimize hardware and software architectures, the following requirements must be satisfied:

### *2.1. Functional Requirements:*

The system's functional requirements are as follows:

• A two-way communication channel must be estab- lished between the H-Gateway and the U-Server using the GSM modem.

• Using the established channel, the H-Gateway must be able to get the forecasted peak intervals for the next day from the U-Server.

• The microcontroller needs to store the readings of the power consumption, measured by the instrument transformers.

• The microcontroller must take appropriate decisions, based on the peak intervals, to supply, use and control the alternative energy sources.

• The stored reading of the power consumptions must be sent from the H-Gateway and stored at the U-Server database.

• The software at the U-Server side must be running 24/7 to parse the readings received by the GSM modem and store them in the database accordingly.

• A Website must be hosted at the U-Server side to provide an interface for the home users to view their power consumption behavior.

• Extra layer of service can be added to control the loads at the house using SMS messages.

### *2.2. Non-Functional Requirements:*

The nonfunctional requirements of the system are concentrated more on the reliability and the maintainability of the system. Moreover, the look and feel of the provided services, such as the website, has to be user-friendly and accessible by all users. Finally, loading the web pages from the Web Server needs to be fast; hence hosting the Website in a near location.

## 3. Proposed System Hardware Architecture

Based on the systems requirements, the proposed system hardware should have two basic building blocks namely; the H-Gateway and the U-Server. Fig. 2 shows the system hardware architecture.

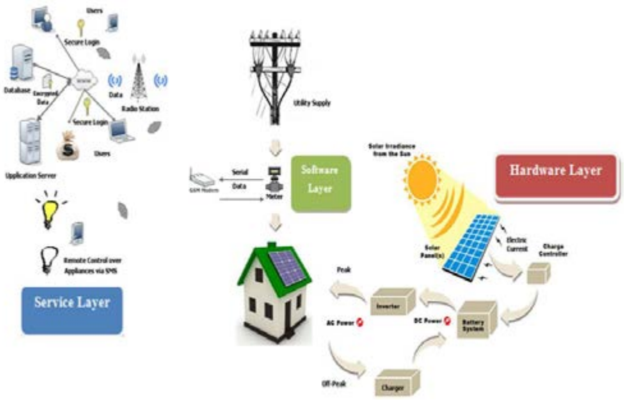


Fig. 2. Proposed system hardware architecture.

The H-Gateway block consists of a solar cell, charge converter, battery, DC/AC inverter, energy meter and GSM modem. Details of the actual system hardware are shown in Fig. 3.

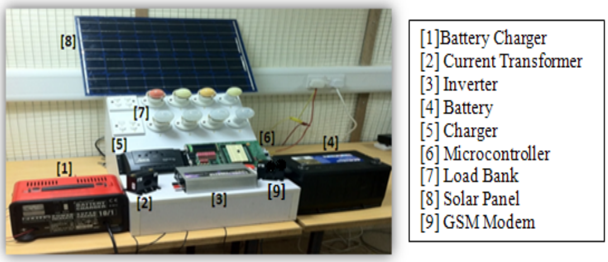


Fig. 3. Experimental setup

The house gets its power from two sources namely; the power grid and the solar cell. The solar cell energy is stored in a battery and then inverted to AC power. The battery can be charged from the solar cell whenever the sun is shining and from the power grid during the off-peak hours if needed. Scenarios for the charging and switching between the alternative power and grid power will be discussed in a later section. The GSM modem is used to provide the communication between the home owner and U-Server. It utilizes the public mobile networks that are managed by the mobile telephone service provider.

The U-Server block is located at the utility headquarter. It is a high-end PC with internet access. It hosts the developed energy management system software. Utility personal and home owner are profiled in a way that allows accessing the server and the H-Gateway via the World Wide Web and mobile public networks. Each user has logon user name, password and level of privilege. The server software activities will be described in later section. Fig. 2 shows the system hardware layout.

## 4. Proposed System Software Model

The proposed system software is divided into three main functions: Energy-Flow-Control, Communication, and Service modules. The following is a brief description of each:

### 4.1. Energy-Flow-Control Module

This module consists of three functions. It is installed in the H-Gateway controller at home:

- Random_Behaviour() function: it assigns some random behaviors to the loads; to simulate the loads at the house.
- Get_Power() function: it reads the current to calculate the power and hence the energy consumption.
- Switch_Source() function: it connects the load to the grid or to the alternative sources based on the peak hours.

### 4.2. Communication Module

The primary function of this module is to provide the communication between the H-Gateway and U-Server to enable the homeowner and utility. It is used to exchange messages and commend to better optimize the home energy consumption. Below is a short description to each function.

Connect_GSM() function: establish a two-way communication between the H-Gateways and the U-Server using the GSM modem.

Send_Peak_Hours() function: send the peak hours from the U-Server database to the GSM modem at the H-Gateway.GSM modem.

Receive_Peak_Hours() function: receive the peak hours from the U-Server and store them in the microcontroller for controlling purposes.

Send_Consumptions(int[] consumption) function: sends the power consumption as an integer array of 24 element, each representing 1 hour of the 24 hours.

### 4.3. U-Service Module

This module is developed and stored in the U-Sever. The following is brief description of this module:

- Store_Readings(int[] consumption) unction: store the readings in the appropriate record in the database at the U-Server.
- Display_Consumption() function: display the power consumption for the user on the Website.
- Create_User() function: creates a user and store his/her information in the database.
- SMS_Control(): control the loads in the house via SMSs.

## 5. Energy Flow Scenarios

The communication between the utility and consumers decides the system action of sequences. As it is showing to figure 4, the following sequence of actions take place to better manage and optimize the power consumption:

- First establishes the communication between the H-Gateway and U-Server using the GSM modem.
- Then, the microcontroller will ask for the forecasted peak hours for the coming day, in order to control the power sources appropriately. Also, the U-Server will be updating the database for the peak

hours every day, and it will send those values to all H-Gateways for all customers.

- After that, the microcontroller will make decisions, based on the retrieved peak hours, to supply power to the load from the grid, alternative sources or both. It will also determine when to charge the batteries and when to use its power.
- Readings of the power consumption will also be taken and stored by the microcontroller. At the end of 24 hours, those values will be sent to the U-Server and the information will be processed and stored in the correct record in the database.

For the services that will be provided for the customers, the customers will be able to retrieve their bills and consumption behavior from the Website. Different types of charts for consumers' consumption will be displayed in order to give the homeowner more information on how to manage his/her power consumption. The homeowners will also be able to control a specific load in their houses via SMS message. The message will be received by the H-Gateway and will be processed to turn ON/OFF any desired load. Fig. 4 shows the system sequence diagram.

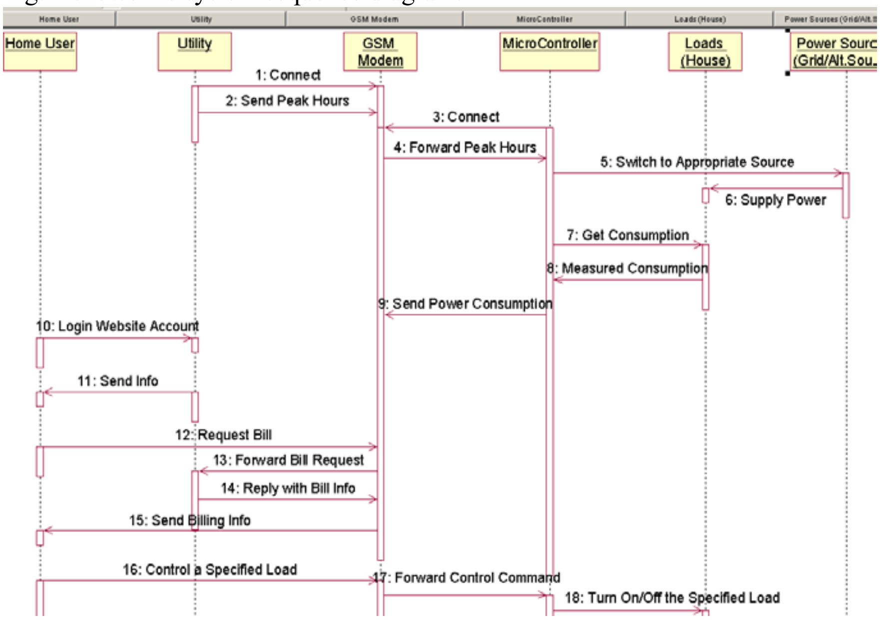


Fig. 4. The system sequence diagram.

## 6. Implementation and Testing

In this study, the price model of Energy Australia demand intervals has been adapted [9]. The pricing intervals appear with the corresponding price model of cent/KWh is shown in Table 1.

The system was run for three different random consumption behaviors with a fixed pricing interval. Figs. 5-7 show a time scaled simulation for the house consumption before and after applying the system to the load bank. The blue bars show the house demand curve before using the system, while the yellow bars show the house demand curve after using the system.

The pricing of each figure is based on Table 1. As indicated previously, the price model was adopted from Energy Australia peak intervals. The pricings are kept in Australian Dollar, AUD. The following Cumulative Distribution Function (CDF) figures (Figures 8-10) correspond to the previous simulated load curves respectively. It is evident from Figs. 8-10 that a reduction in the consumer bill of 33.5%, 35.7%, and 32.23% respectively has been achieved.

Table 1. Pricing Intervals

| Time | Rate in cents/kWh |
|---|---|
| Peak (2pm - 8pm) | 40.04 |
| Shoulder (7am to 2pm and 8pm to 10pm) | 14.85 |
| Off-peak (all other times) | 8.36 |

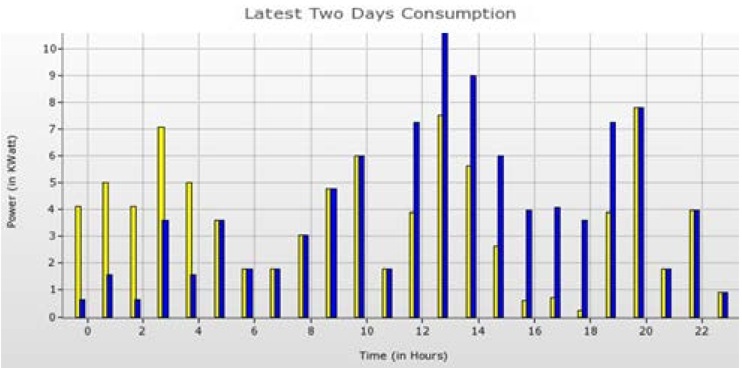


Fig. 5. First simulation

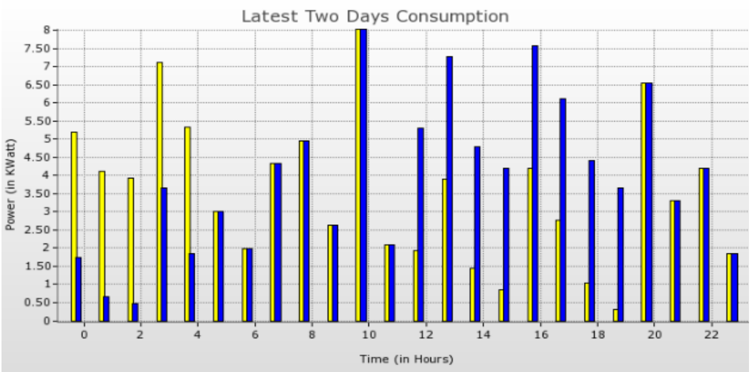


Fig. 6. Second Simulation

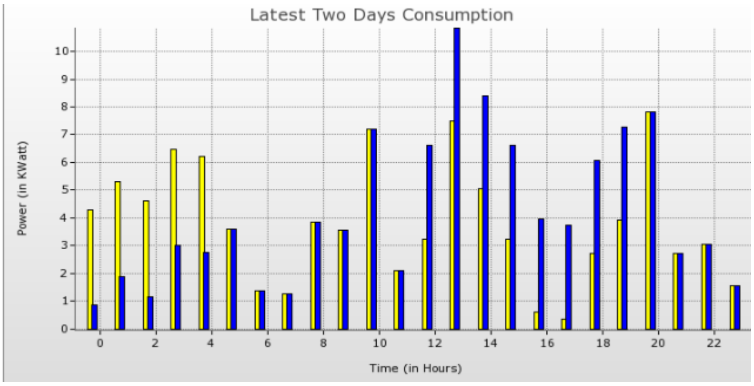


Fig. 7. Third Simulation

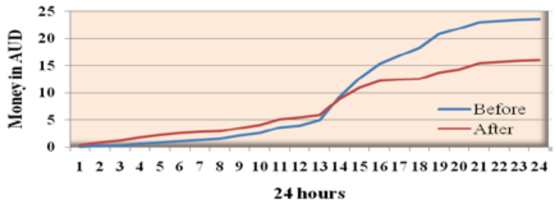

Fig. 8. CDF pricing chart for first simulation

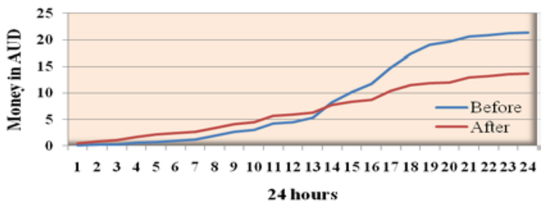

Fig. 9. CDF pricing chart for first simulation

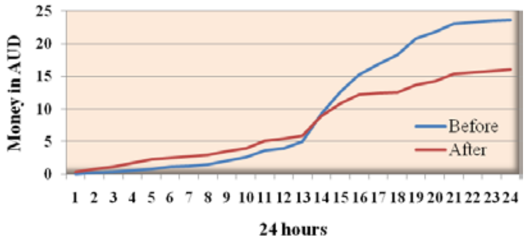

Fig. 10. CDF pricing chart for first simulation

## 7. Conclusion

A renewable energy resource was integrated with the public power grid to better manage smart home power consumption. Switching between the power from the grid and the renewable energy resource controller was designed, implemented and tested. It was proven that communication between the utility server and home gateway result in managing the peak. Integrating the renewable energy source saved about 33% of the home energy bill.

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